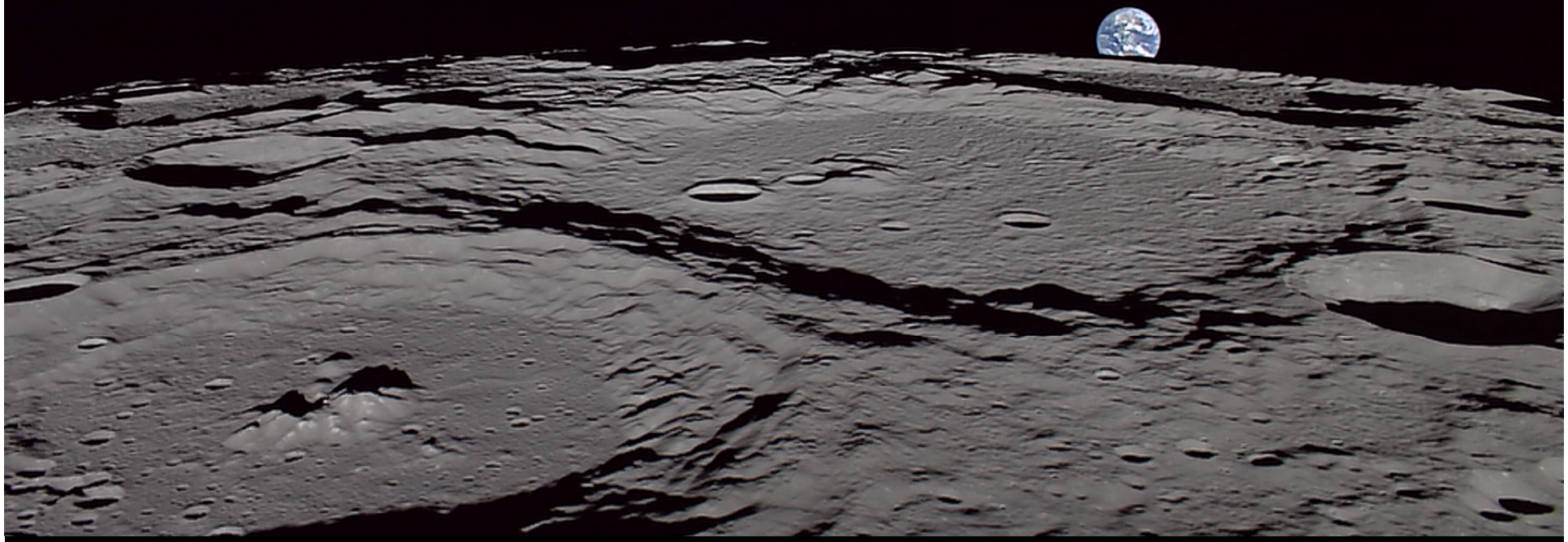
The Moon as an Enabling Asset for Spaceflight



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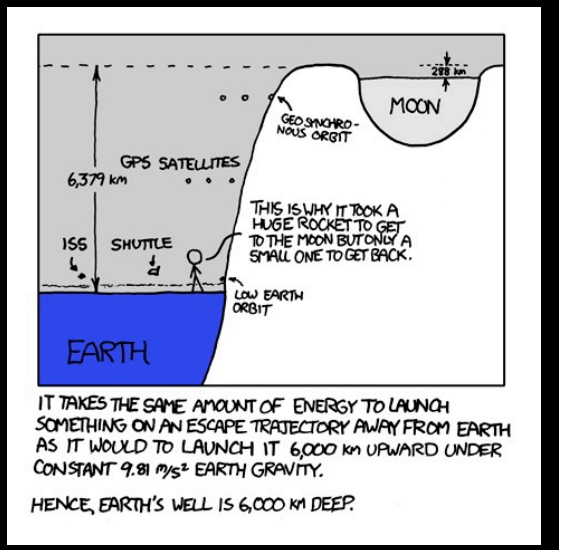
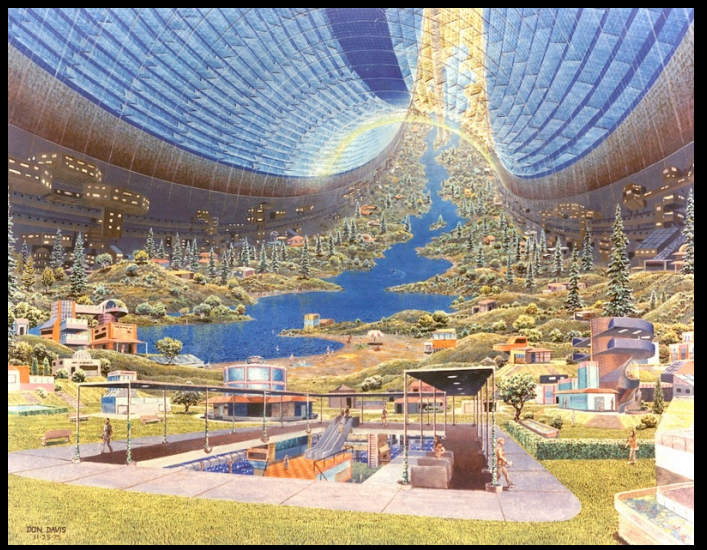
22 July 2014

Our Dilemma

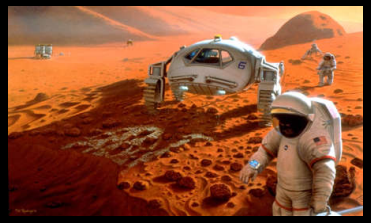
- Humans in space for more than 50 years, but template has not changed
  - Launch, use, discard
  - No permanent space-based infrastructure
  - All “dumb mass” consumables (propellant, life support) must be lifted from deepest gravity well in the inner Solar System
- An alternative model
  - Space-centric, not Earth-centric
  - Dumb mass supplied from local resources
  - Continuously expanding sphere of human reach
  - Wide variety of activities, not just science or exploration

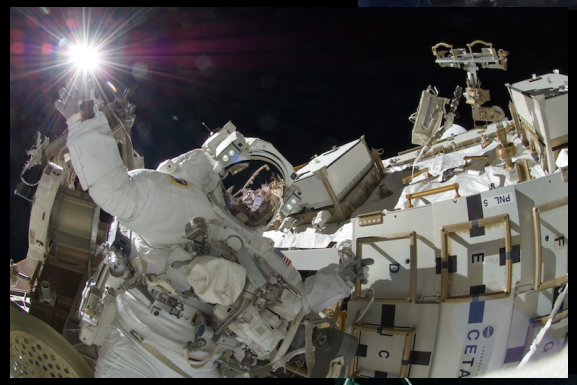




What's Our Objective in Space?

- Contrary to conventional wisdom, it is *not* simply "Humans to Mars"
  - That is just one of many different objectives
  - Apollo-like program and architecture is likely to suffer the same type of ending
- **The ability to go anywhere, for any length of time, to do whatever job we can imagine**
  - Freedom of movement throughout the Solar System
  - As long as we are limited to only what we can launch from Earth, we will remain mass- and power-limited than therefore, capability-limited
  - Analogy is to seafaring, not aviation





So What's the Problem?

Spaceflight is difficult

- The Tyranny of the Rocket Equation
- Reaching LEO with empty fuel tanks

Spaceflight is expensive

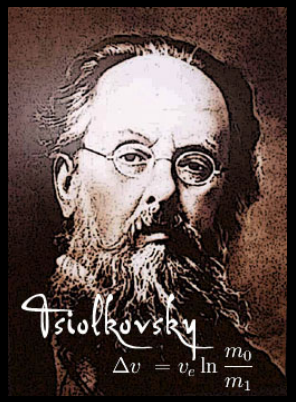
- Accelerating tons of mass to Mach 25 and lifting it hundreds of km
- Precision machining, complex avionics, difficult-to-work materials

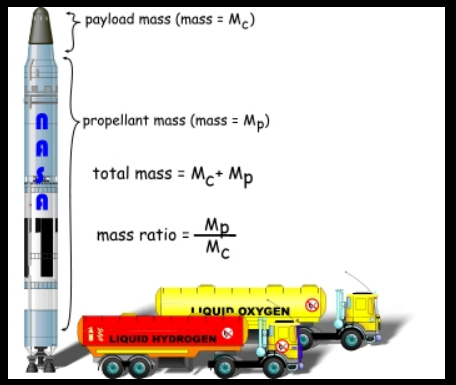
Spaceflight is barely possible

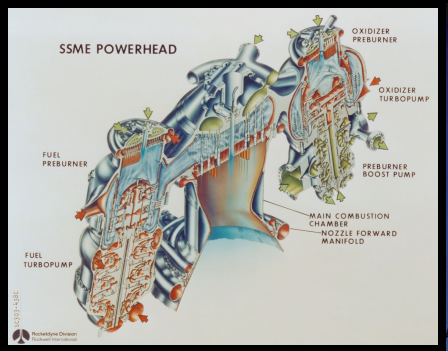
- If radius of Earth were 50% larger, the energy in chemical bonds would not be sufficient to reach orbit

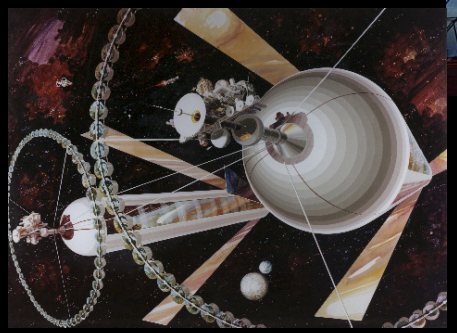
The benefits of spaceflight are not intuitively obvious

- Human destiny, species survival, "Because it's there.." are not typical justifications for massive amounts of federal spending



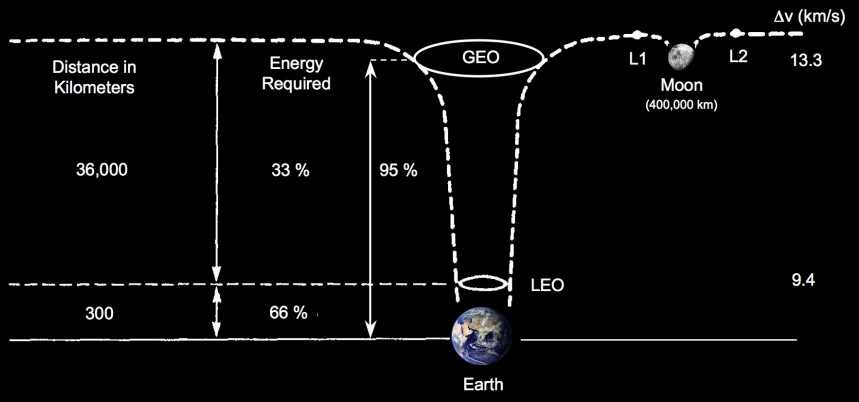






Or to put it another way….

- If our ultimate goal in space is to go anywhere, anytime with as much capability as we need…
- And spacecraft are mass- and power-limited and thus, capability-limited…
- And they will remain so as long as we are restricted to what can be lifted out of Earth's gravity well…
- And this restriction negatively impacts scientific capabilities, economic health, and national security…

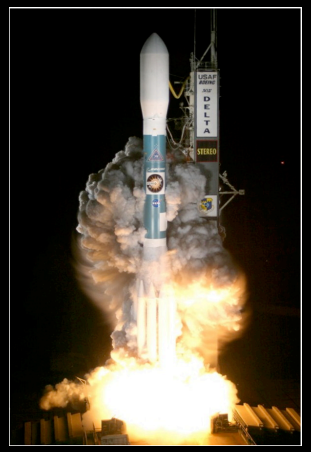


Then to extend reach and capability, we must learn to use what we find in space to create new space faring capabilities

Space faring: Changing the Rules

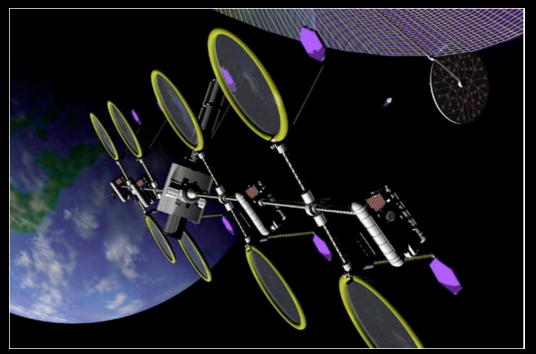
Current template

- Custom-built, self-contained, mission-specific spacecraft
- Launch on expendable vehicles
- Operate for set lifetime
- Abandon after use
- Repeat, repeat, repeat



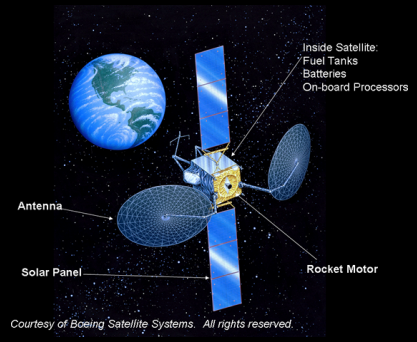
New template

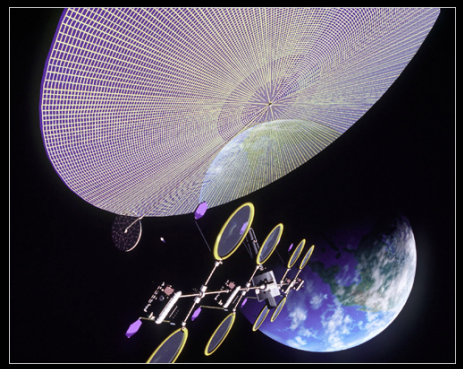
- Incremental, extensible building blocks
- Extract material and energy resources *of* space to use *in* space
- Launch only what cannot be fabricated or built in space
- Build and operate flexible, modular, extensible in-space systems
- Maintain, expand and use indefinitely



The Value of Space to Modern Life

- Modern industrial civilization depends critically on numerous satellite assets in high orbits above LEO:
  - GPS and navigation
  - Global communications
  - Remote sensing, weather
  - Surveillance and national security assets
- We cannot access those satellites to maintain them or to build large, distributed space systems
- If we could access those satellites with humans and robots, new capabilities from space assets could be created, ensuring ourselves a better quality of life, a bigger and stronger economy, and a more secure world



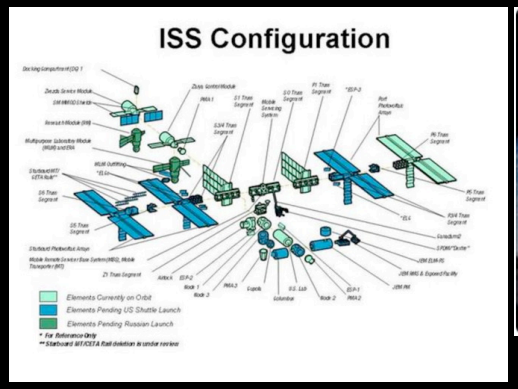


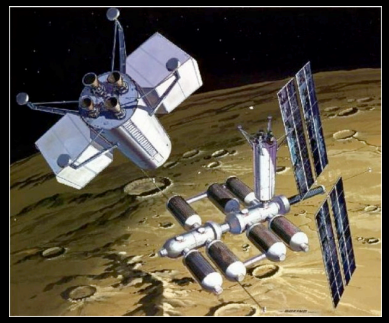
Lessons from Shuttle and Station Programs

Large, distributed systems too big to be launched from Earth can be assembled in space

Humans and machines working together can assemble, service and maintain complex space systems

Applying this paradigm to trans-LEO (cislunar) space requires development of a transportation system that is affordable, extensible, and reusable





Developing the resources of the Moon enables the creation of such a system (if you can reach the lunar surface, you can access any other point in cislunar space)

Why the Moon?

It's close

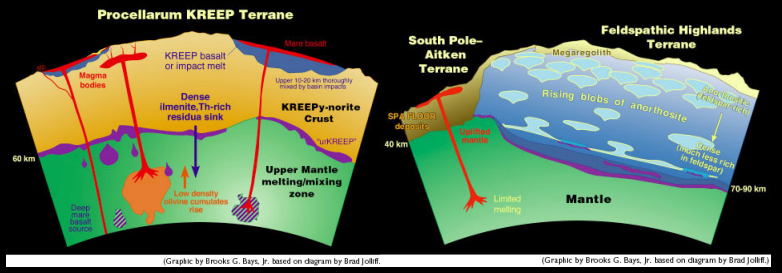
- Three days away and easily accessible (as near as GEO)
- Transport system to Moon can also access GEO, cislunar, Earth-Sun Lagrangians, and some asteroids

It's interesting

- Moon contains a record of planetary history, evolution and processes unavailable for study on Earth or elsewhere

It's useful

- Retire risk to future planetary missions by re-acquiring experience and testing with lunar missions
- Development of lunar resources has potential to be a major advancement in space logistics capability



The Value of the Moon

Proximity

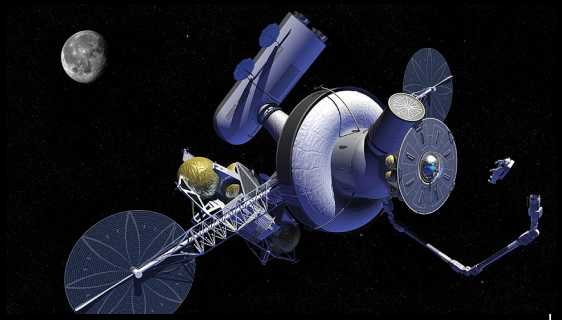
The Moon is in Earth orbit and thus constantly accessible from Earth; multiple launch windows always available

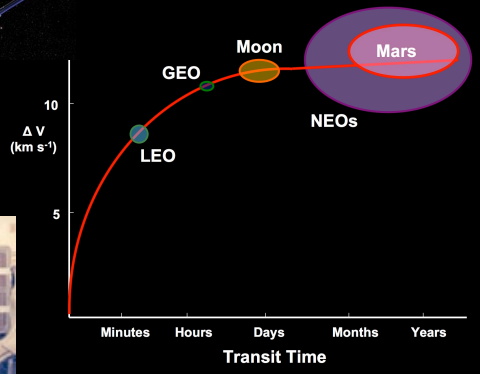
Ease of access

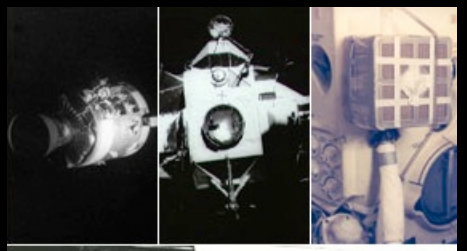
- Δv LEO to lunar surface ~6 km/s (to martian surface ~10 km/s)
- Transit time: 3-5 days
- Transit using WSB: weeks

Multiple options for mission abort and rapid Earth return

Round-trip light time permits near-real time control of machines from operators on Earth



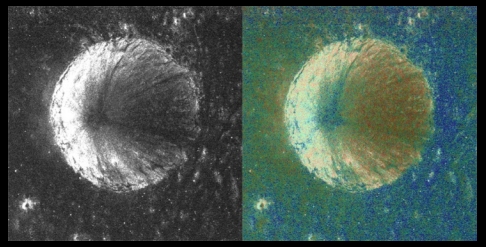


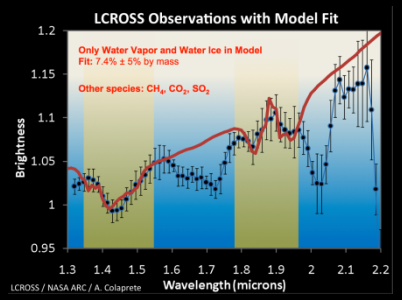


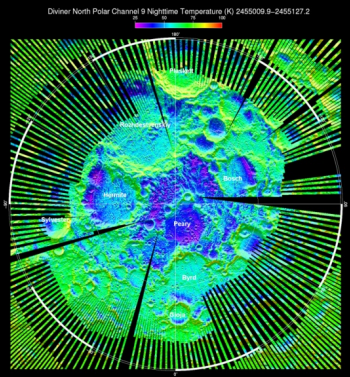
The Value of the Moon

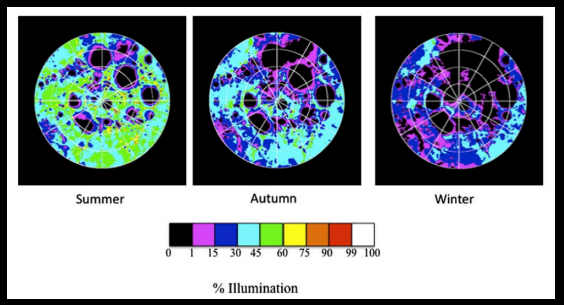
Utility

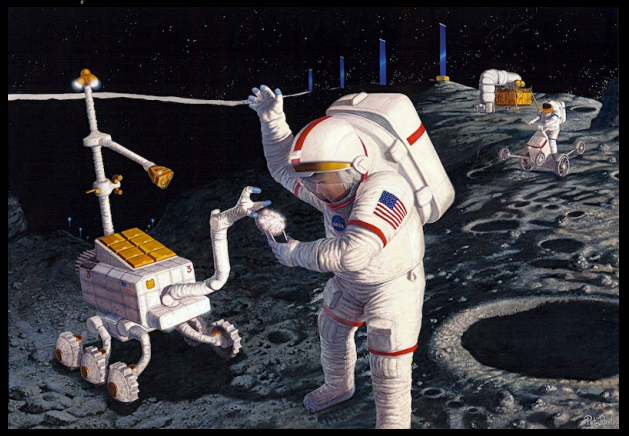
- Material resources
  - Bulk regolith (shielding, ceramics, aggregate for construction)
  - Metals (iron, aluminum, titanium)
  - Water (chemically unbound)
- Energy resources
  - Areas near poles in quasi-permanent sunlight, close to water deposits
- Environmental resources
  - Thermal cold traps (~30-40 K)
  - Hard vacuum (10^{-9} torr)
  - Fractional gravity (0.17 Earth)
- Operational resources
  - Planetary environment to learn optimal exploration strategies
  - Technology test-bed for planetary surface systems





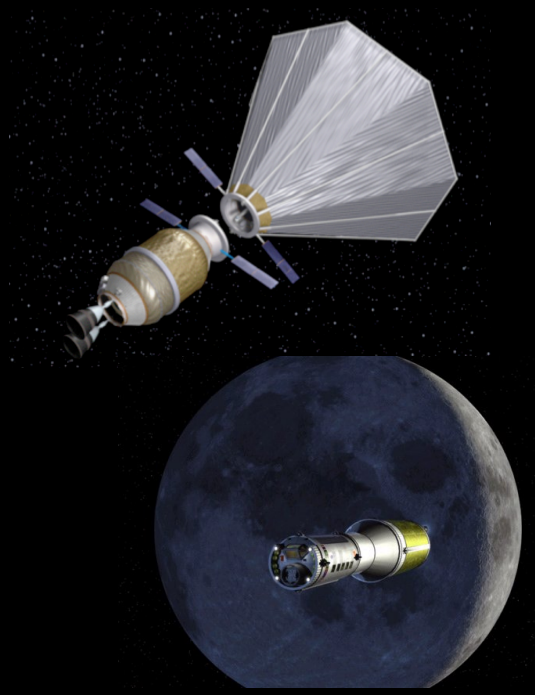


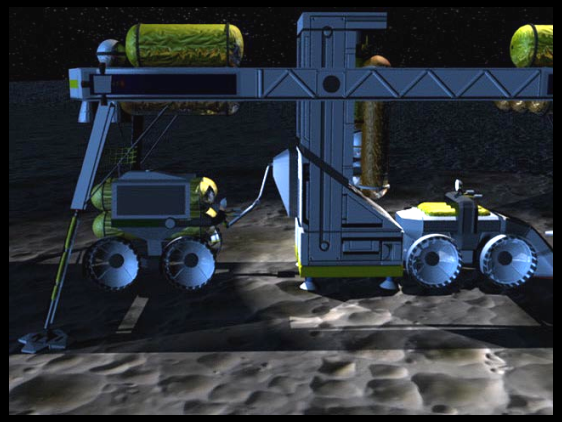




Goals and Principles

- Extend human reach beyond LEO by creating a permanent, extensible space faring infrastructure
- Use the material and energy resources of the Moon to create this system
- Lunar return by small, incremental, cumulative steps
- Proximity of Moon permits progress prior to human arrival via robotic teleoperations
- New and innovative space systems: fuel depots, robotics, ISRU, reusable spacecraft, staging nodes
- Fit under reasonable budget (e.g., estimated run-out of Augustine Committee, 2009)
- Schedule is free variable; constant, steady progress but no deadlines





An Affordable Lunar Return Architecture

Mission

- Create a permanent human-tended lunar outpost to harvest water and make propellant

Approach

- Small, incremental, cumulative steps
- Robotic assets first to document resources, demonstrate production methods
- Teleoperation of robotic mining equipment from Earth. Emplace and build outpost assets remotely
- Use existing LV, HLV if it becomes available

Cost and Schedule

- Fits under existing run-out budget (< $7B/year, 16 years, aggregate cost $88 B, real-year dollars)
- Resource processing outpost operational halfway through program (after 18 missions); end stage after 30 missions: 150 mT water/year production

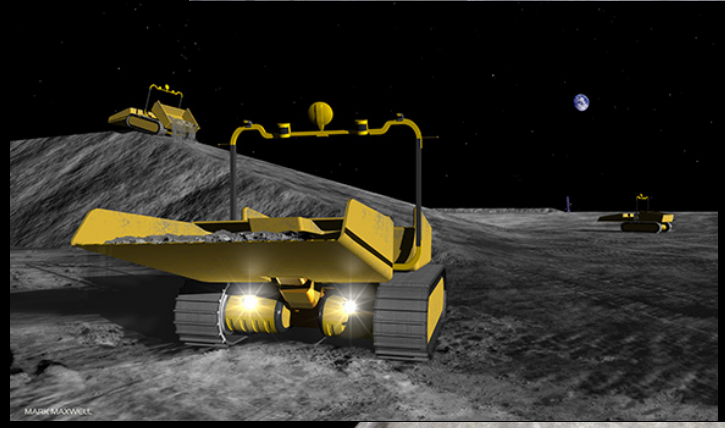
Benefits

- Permanent space transportation system
- Routine access to all cislunar space by people and machines
- Experience living and working on another world

P.D. Spudis and A.R. Lavoie (2011) Using the Resources of the Moon to Create a Permanent Cislunar Space Faring System. Space 2011 Conf, Long Beach CA, AIAA 2011-7185, 24 pp.

What would such an approach give us?

- A permanent, cislunar space transportation system based upon the harvest and use of lunar water
- Most infrastructure is emplaced and operated robotically; people come when facilities and budgets are ready
- Small incremental steps that build upon each other and work together
- Progress continually made, regardless of budgetary issues in any given year
- Incremental approach greatly facilitates both commercial and international participation
- Cislunar transportation system is a “transcontinental railroad” in space, opening up the frontier



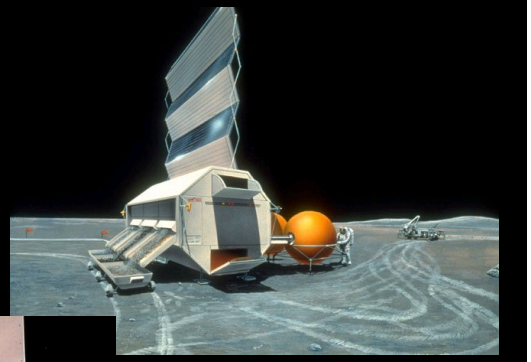
The Moon: An Enabling Asset

A testing and training ground for future human missions

- Develop and test technology, equipment and flight elements on Moon and in cislunar space
- Rehearse mission operations, simulate conditions, practice contingency procedures
- Learn how to best explore planetary surfaces with an optimum mix of humans and robots

A logistics depot for continuing flight capability

- Water, the most useful substance for spaceflight, available in quantity
- Near-continuous power from sunlight near lunar poles
- Presence in Earth orbit assures routine, continuous and easy access from Earth and variety of other locations in cislunar space



What Kind of Space Program?

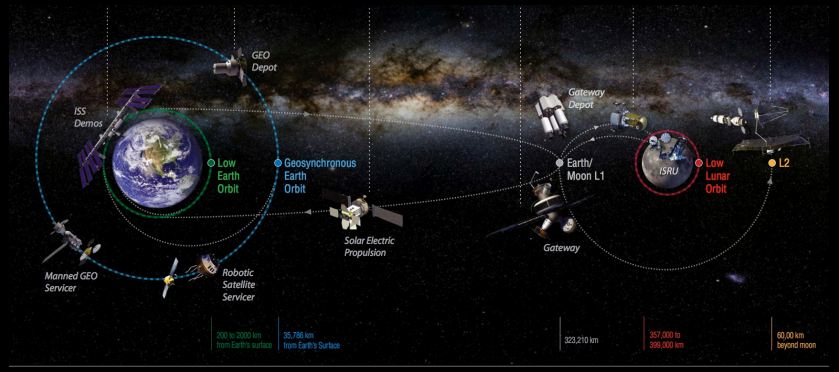
Two Visions

"A spectacular series of space 'firsts'" (Augustine report, 2009)

- Launch, use and discard
- Everything comes up from Earth
- One-off, PR "stunt" missions
- Accomplish the feat and cancel the program
- Flags and footprints forever
- Costly and subject to political and fiscal winds of change

Become a true space faring species

- Reusable, maintainable, extensible space systems
- Incremental, cumulative, steady progression outward
- Fit under any budget envelope; return value for money spent
- Government develops and demos technology; commerce follows
- Create a permanent and expanding space transportation infrastructure
- Less glitter, more substance



Space – A New Rationale

"If God wanted man to become a space-faring species, He would have given man a Moon." – Krafft Ehricke

Explore to broaden our knowledge and imagination base

Prosper by using the unlimited energy and materials of space to increase our wealth

Secure our nation and the world by using the assets of space to protect the planet and ourselves